

LEADERSHIP, COORDINATION AND MISSION-DRIVEN MANAGEMENT*

Patrick Bolton[†]
Columbia University

Markus K. Brunnermeier[‡]
Princeton University

Laura Veldkamp[§]
New York University

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Abstract

What makes a good leader? A good leader is able to coordinate his followers around a credible mission statement, which communicates the future course of action of the organization. In practice, leaders learn about the best course of action for the organization over time. While learning helps improve the organization's goals it also creates a time-consistency problem. Leader resoluteness is a valuable attribute in such a setting, since it slows down the leader's learning and thus improves the credibility of the mission statement. But resolute leaders also inhibit communication with followers and leader resoluteness is costly when followers have sufficiently valuable signals.

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[†]Department of Economics and GSB, Columbia University, New York, NY 10027, e-mail: pb2208@columbia.edu, <http://www0.gsb.columbia.edu/faculty/pbolton>

[‡]Department of Economics, Bendheim Center for Finance, Princeton University, Princeton, NJ 08544-1021, e-mail: markus@princeton.edu, <http://www.princeton.edu/~markus>

[§]Department of Economics, Stern School of Business, New York University, New York, NY 10012-1126, e-mail: lveldkam@stern.nyu.edu, <http://pages.stern.nyu.edu/~lveldkam>

“Consistency of word and deed on the leader’s part is absolutely necessary if others are to commit themselves to the personal and business risks associated with new and unproven courses of action. The general manager who runs hot and cold will fail to encourage confidence in others. ... Nobody wants to go out on a limb and risk being abandoned at the first sound of cracking wood.” Aguilar (1988)

1 Introduction

In this paper we consider a model of leadership in organizations. The role of leadership we focus on is that of helping coordinate the actions of the different members of an organization. The role of the leader is to give a sense of direction for the organization. The leader evaluates the environment in which the organization operates and determines the best strategy adapted to that environment. The leader’s dilemma is that he would like to base the organization’s focus (or mission) on all the relevant information about the environment available to him. But, since information about the environment only trickles in over time, the leader may then be led to revise the organization’s direction as new information becomes available. His desire to modify the direction of the organization over time thus undermines his ability to coordinate the actions of the other members of the organization.

In other words, the essence of the leadership problem in our model is to reconcile the adaptation to a changing environment—which requires information acquisition and revision of the organization’s strategy in response to new information—and coordination of the actions of the other members of the organization. Thus, the main question we are interested in here, is determining which attributes of a leader are most desirable in balancing the need for adaptation with coordination.

Our leadership problem can be captured in a simple setup involving four stages. In the first stage the leader observes a first signal of the environment (or state of nature) the organization is likely to be in. Based on that signal the leader can define a mission

or overall strategy for the organization. In a second stage, the other members of the organization – the followers – decide how closely they want to stick to the leader’s strategy. They may not be inclined to blindly follow the leader’s proposed strategy because they also observe signals about the state of nature, and they may come up with different forecasts of what the ultimate direction for the organization will be. In a third stage the leader receives a second signal. This signal could be an aggregate of the signals of the followers or simply new information that becomes available. The leader implements the organization’s strategy given all the information he has available. Since the followers have already acted, the leader at this point is no longer concerned about coordinating their actions. The leader’s only remaining goal is to adopt a strategy for the organization that is best given all the information he has. In the fourth and last stage, once the strategy has been implemented, the organization’s payoffs are realized. These will be higher the better adapted the strategy is to the environment and the better coordinated all the members’ actions are.

In this setup, the followers in the organization may be concerned about two potential flaws in leadership: one is that the leader misdiagnoses the circumstances the organization finds itself in and chooses a maladapted mission for the group; the other is that the mission is incoherently implemented with substantial coordination failures.

What makes a good leader in such a situation? We argue that a key attribute of a good leader is a form of overconfidence, which we shall refer to as *resoluteness*. A *resolute* leader has a strong prior and is slow to change his mind in the face of new information about the environment in which the organization operates. A resolute leader attaches an exaggerated information value to his initial information, or on the signals he processes himself. In other words, a resolute leader trusts his own initial judgement more than an open-minded, rational leader, and also more than that of other members of the organization. He then tends to define a strategy for the organization based disproportionately on his own best initial assessment of the environment the firm

finds itself in.

The reason that such resoluteness is valuable is that the conflicting desires to coordinate followers and adapt the mission create a time-consistency problem. The leader would like to followers to believe that his mission statement is what he will ultimately implement. But followers know that ex-post the leader will want to revise the organization's strategy in response to new information after they have acted. This is what causes them to be insufficiently coordinated, as each attempts to guess how the leader will revise the organization's strategy in light of what they know about the environment. A resolute leader who puts too little weight on new information from other members is more likely to follow through with the initial mission, which helps coordinate followers' actions around that mission. We show that this coordination benefit outweighs the potential maladaptation cost as long as the leader's determination is not too extreme.

While resoluteness helps a leader to commit to "staying the course" it also raises the risk for the organization of pursuing the wrong strategy. One might wonder, therefore, whether there aren't better ways of achieving commitment, without at the same time putting too much weight on the leader's initial beliefs. If a rational leader were able to commit to a strategy for the organization in the first stage by, say, staking his reputation on pursuing a clearly defined mission, in a manner similar to President George H.W. Bush's announcement, "read my lips: no new taxes", wouldn't that be a superior form of commitment? It turns out that even when such a commitment technology is available, a resolute leader still outperforms a rational one, since an unwavering leader makes a stronger mission statement but incurs less of the commitment cost.

Finally, we consider an extension where the leader learns about the environment by observing followers' actions, which imperfectly convey their signals. That is, in addition to top-down information flow, we also allow for bottom-up information flow. In such a situation it is more important for the leader to let followers' base their actions on the

signal they observe, so as to transmit more information back to the leader. Since less coordination brings about better adaptation, observing actions moderates the benefits of resoluteness. In other words, *resolute managers make bad listeners* and learn little. A leader’s failure to listen to followers is especially costly when followers have very precise information.

The second main result is that observing followers’ actions creates a feedback effect that can generate multiple equilibria: If followers expect the leader to ignore the information from their actions, then the leader’s initial announcement is the best estimate of his final action. If followers use only the announcement and not their private information in forming actions, then the leader rightly ignores the aggregate action because it is uninformative. On the other hand, if followers expect the leader to listen carefully to the average action in forming policy, then they want to use their private signals to forecast the policy change. Actions reflect their information. An organization’s corporate culture could determine which equilibrium prevails. Thus, our framework captures one aspect of corporate culture.

Most surprisingly, a resolute leader who acts as though he has precise information might be a better leader than a more competent leader who is really better informed. A leader whose competence is known may induce followers to rely only on his mission statement, whereas a less competent but resolute leader could prompt followers to use their private information, improving bottom-up information flow and managerial decision-making.

Interestingly, in a first study of CEO characteristics based on a detailed data set of candidates for CEO positions in private equity funded firms, Kaplan, Klebanov, and Sorensen (2007) find evidence consistent with our model predictions. Mainly, they find that although companies tend to prefer hiring “team-players” at equal levels of ability, CEOs with – in their terminology – “hard/execution related skills” tend to outperform CEOs with “soft/team related skills”. Or, in our terminology, more resolute, steadfast,

CEOs, who stick to their guns, tend to be better leaders than “good listeners”.

An apt recent example of a business leadership situation that our model attempts to capture is that of Sony Corporation. At the time when Sony recruited its new CEO, Sir Howard Stringer, it faced major new challenges. Its old business model, electronics appliance manufacturing, had been threatened by the spread of personal computers and the growing importance of internet applications and software development. Its leadership in portable electronic devices had been challenged by Apple and its strong presence in the game-console markets was under threat from Microsoft’s X-box.

To be able to maintain its competitive position, Sony’s new leader needed to accomplish both of the objectives our model identifies: adapt to changing circumstances and coordinate many actors. To adapt, Sony felt that it needed to change direction and re-focus its operations around a new mission. The appointment of Howard Stringer was seen as an important step towards this transformation. Howard Stringer and top Sony management put together a major new strategy centered around the expansion of high definition digital technology and the development of Sony’s new Blu-ray standard.

The success of this change in strategy depended critically on how effective Sony was in convincing consumers, movie producers, software developers, investors and Sony’s own engineers and product managers that Sony’s new HD technology would be successful. The credibility of the strategy would determine the responses of competitors such as Apple and Microsoft, the rate of technological innovation in media technology, and the eventual outcome of the standards war between Blu-ray and HD DVD.¹ In implementing his strategy, the challenge Stringer needed a clearly defined and credible mission that effectively coordinated many different parties around this new strategy.

The main thrust of our argument is that if Howard Stringer was able to convey his faith in the technology and the success of Sony’s overall strategy, and if he could credibly signal his determination in carrying through the overall plan, he would be able to

¹See “In Blu-ray Coup, Sony Has Opening But Hurdles, Too” by Sarah McBride, Yukari Iwakane and Nick Wingfield, 7 January 2008, *Wall Street Journal*.

substantially increase Sony's chances of succeeding. The benefit of his resolute leadership style would be that he could make it easier to coordinate Sony's multiple divisions, and also the decisions of outside software and content developers, thus increasing the value of the new technological platform. The downside of his single-minded pursuit of this mission, would, of course, be that by firmly rallying the whole organization around the new Blu-ray technology he could risk committing the whole corporation to an obsolete or losing technology.

2 Related Literature

There is a small but rapidly growing economics literature on leadership. Most of this literature, however, deals with different facets of leadership. One of the earliest contributions is by Rotemberg and Saloner (1993), who address the question of how a leader can motivate followers to exert effort and come up with proposals for improvements in the firm's operation. Followers value the fact that their proposals are taken into account and are adopted by the leader. They are therefore willing to exert (unobservable) costly effort to come up with proposals if they expect that there is a reasonable chance that they will be adopted. Rotemberg and Saloner consider two leadership styles. One is where the leader maximizes profits, and the other where managerial decision-making is more sensitive to the preferences of employees. They show that the latter approach can ultimately lead to higher profits, as it induces employees to exert more effort and thus brings about more improvements. In a subsequent related article, Rotemberg and Saloner (2000) also allow the leader to encourage employee effort by ruling out possible future courses of action, so that employees are better able to determine what kinds of initiatives will be favored. Ruling out certain activities amounts to defining the organization's focus. In this respect the leader's objective of delineating the scope of the organization in Rotemberg and Saloner (2000) is similar to the leader's objective of proposing a consistent plan in our setup. But, instead of asking how to maximize

employee effort as in Rotemberg and Saloner, we ask a different question: What kind of leader best coordinates followers' actions?

Hermalin (1998) considers the role of leadership by example in a moral hazard in teams problem where organizational output depends on all members' efforts and where all members share the aggregate output. As is well known, in a team production problem, individual team members may free-ride on other team members' efforts. Thus, the leader's problem is to motivate team members and help overcome free-riding. Hermalin assumes that the leader has private information about the return to effort and argues that the leader will then tend to overstate the return to effort so as to mitigate free-riding. He will be able to motivate other team members to put in effort by leading by example and exerting himself. Hermalin does not allow for leader steadfastness, but his notion of leading by example is related to our conception of leadership as giving a sense of direction to other organization members.

Another recent model of leadership in organizations by Majumdar and Mukand (2007) also focuses on the leader's role in coordinating the actions of multiple followers. In their model the leader is able to coordinate agents if he is thought to be able to correctly identify circumstances when change is possible, and if he is able to communicate with a sufficiently large number of followers. Unlike in our model, their analysis does not address the issue of leadership characteristics, such as resoluteness, and it does not allow for a commitment problem for the leader.

Coordination also plays a central role in Dewan and Myatt (2007). This paper argues that the leader's clarity in communication is relatively more important than giving a sense of direction. Their static model does not address the time consistency problem that is central for our results.

Similarly, Ferreira and Rezende (2007) consider a related leadership problem in a two-period and two-signal realization model, where the leader is trying to both induce a complementary action by a follower and to adapt the firm's strategy to the firm's

environment in the second period. Again, however, they do not focus on leader characteristics (such as resoluteness) and instead focus on the question of the desirability of using public disclosure of the firm's strategy as a commitment device.

A handful of papers explore the role of overconfidence in leadership. In Van Den Steen (2005), managerial overconfidence helps attract and retain employees with similar beliefs. The resulting alignment of beliefs helps firms function more efficiently. In particular when similar followers and managers are paired, the manager is more likely to implement projects or ideas proposed by an employee (which provides private benefits to the employee). As in Rotemberg and Saloner, employees are then induced to put in more effort to identify new projects, which benefits the organization.

Goel and Thakor (2008) study a model of managerial promotions and provide an explanation for how companies tend to appoint overconfident CEOs. They consider a model where managers with unknown ability compete for leadership. In their model managers make the best available project choices and the manager with the best project outcome is selected as leader. They show that overconfident managers tend to make riskier project choices and are therefore more likely to be selected as leader. Similarly, Gervais and Goldstein (2007) introduce overconfidence into a moral hazard in teams problem akin to Hermalin (1998). In their model an overconfident leader tends to work harder and thus induces all other team members to coordinate around a higher effort choice. Unlike in our model, however, they do not consider the time-consistency problem of the leader and how resoluteness can mitigate this problem.

Finally, the study by Blanes I Vidal and Möller (2007) also emphasizes the potential benefits of leader overconfidence. They study a similar problem of information communication as Ferreira and Rezende (2007) in a static leader-follower setup. The benefit of sharing information in their model is that it helps motivate the follower. But there is also a cost, as the leader may put too much weight on concerns for motivating the follower and too little on making accurate decisions based on her own soft information.

Blanes I Vidal and Möller (2007) then show that in this context leader overconfidence (or, self-confidence in their terminology) may help mitigate the leader’s motivational bias under information sharing.

The model of organizations that is most closely related to ours is that of Dessein and Santos (2006). As in our setup they also consider an organization’s tradeoff between achieving greater coordination and greater adaptation. However, they do not allow for any role for leadership. In their model members of the organization coordinate through direct communication.

The remainder of our paper is organized as follows. Section 2 presents our model of coordination and adaptation for the organization and the role of leadership in an organization facing this tradeoff. Section 3 considers a slightly more general variant of our model, where the leader can obtain information from other members of the organization revealed by their actions. Section 4 concludes with a summary and directions for future research. Finally, an appendix contains the more involved proofs.

3 Coordination vs. adaptation

The tension between coordination and flexibility arises first from changes in the environment, which require adaptation, and second from the gradual arrival of information about the environment. To illustrate this problem we consider a setting where the leader receives an exogenous signal in each of two periods. Based on his initial beliefs, the leader proposes a strategy for the organization and get other members to coordinate their actions around it. But the leader may change his mind and reorient the strategy following the arrival of the second signal. While the ex-post reorientation helps bring about better adaptation, the anticipation of possible changes in strategy also make it harder to coordinate followers’ actions. The reason is that the followers also observe a private signal about the environment and use this signal to forecast possible reorientations of the organization’s strategy.

We show that leader steadfastness is a valuable attribute in such a situation (Section 3.1). The more resolute the leader the less likely he is to change his mind and therefore the less likely is a possible reorientation of the organization’s strategy. Remarkably, resoluteness remains a valuable attribute even when the leader can commit to a strategy by staking his reputation (Section 3.2). We assume for now that signals are exogenous. We explore endogenous signals, derived from the aggregate choice of followers, in Section 4.

3.1 Merits of resoluteness

Model setup The organization we consider has one leader and a continuum of followers indexed by i . The organization operates in an environment parameterized by θ , which affects payoffs and to which the organization must try to adapt as best it can. The difficulty for the organization is that θ is not known perfectly to any member of the organization. The leader of the organization and the other agents (the *followers*) start with different information or beliefs about the true value of θ .

The leader differs from the followers in two ways: first he can define a mission statement for the organization based on his initial beliefs² $\theta_L \sim \mathcal{N}(\theta, 1)$ before the followers obtain their own private information about θ and make their own moves. Second, after the followers have received their own information about θ and have chosen their actions a_i the leader receives further information about θ in the form of a signal S_L . The leader then implements the strategy of the organization a_L based on his updated beliefs about θ .

Followers value three things:

1. taking an action that is close to (or aligned with) the organization’s strategy;

²Note that we do not depart from the common prior assumption, which allows consistent welfare statements. One can think of the initial beliefs as resulting from updating a flat (improper) prior based on an initial signal.

2. belonging to a well-coordinated organization, and
3. belonging to an organization that is well-adapted to its environment θ .

Formally, we represent these preferences with the following objective function for each follower:

$$\Pi_i = -(a_i - a_L)^2 - \int_j (a_j - \bar{a})^2 dj - (a_L - \theta)^2 \text{ for } i \in [0, 1] \cup \{L\} \quad (1)$$

One interpretation of this payoff function is that the followers get a pay raise or bonus for taking an action close to the ultimate policy choice of their organization/firm. In addition, all followers get a share of firm profits, which depends on the accuracy of the firm's stated goal, and on the degree of coordination among followers.

The leader's objective Π_L is the same as the followers and in this respect our model of the organization is essentially a team problem à la Marschak and Radner (1972). However, our model is different in two respects from a standard team problem. First, as the leader is inevitably well coordinated with himself, we always have $(a_i - a_L) = 0$, for $i = L$. Second, to the extent that a well coordinated action a_i by follower i benefits both him and all other members of the organization, there is a coordination externality among all members. And to the extent that the private and public values of coordination are misaligned there is an additional role for leader resoluteness in our model, namely to help internalize this coordination externality.³

Neither the leader nor followers know the true environment of the organization, θ . The leader begins with a prior belief θ_L and updates his beliefs based on a subsequent private signal S_L he independently receives. The leader makes a public announcement

³A separate on-line technical appendix posted on the authors' websites explores alternative payoff formulations. Assigning the leader and the firm the same objective so that they share the concern for misalignment makes the analysis more involved, but leaves our qualitative conclusions unchanged. Similarly, if we weight the three terms of the payoff function unequally, it does not reverse our conclusions. A greater concern for alignment or coordination makes the optimal level of overconfidence higher, while a greater concern for adaptation makes it smaller, but still positive. Finally, the appendix explores different forms of the coordination externality and commitment cost.

of his beliefs as a *mission statement for the organization* before followers act. Followers act in response to the leader's mission statement and to their own information about the environment. For simplicity we assume that followers start with a diffuse prior, which they update using a signal $S_i \sim \mathcal{N}(\theta, \sigma_\theta^2)$ they each privately and independently receive, as well as the leader's mission statement θ_L . Followers are assumed to be all rational and know the true variance of all signals.

The leader's mission statement θ_L is credible because there is no incentive to manipulate the level of followers' expectations. The leader may have a form of overconfidence, in the sense that he may underestimate the variance of his prior beliefs (or overestimate the precision of his prior). More formally, although the prior has a true distribution $\theta_L \sim \mathcal{N}(\theta, 1)$ an overconfident, or *resolute*, leader believes the prior to have a lower variance $\sigma_p^2 \leq 1$.

After followers choose their action a_i but before the leader chooses his action a_L , a signal $S_L \sim \mathcal{N}(\theta, \sigma_L^2)$ is observed by the leader.⁴ We assume that the true and perceived precision of this signal are the same.

The rationale for modeling *resoluteness* as a higher precision of the leader's prior, is most clear in Section 4, when the signal S_L is generated by other agents' actions. In essence, resoluteness in our model means that a leader trusts his own judgement more than the information acquired from others. But for now, the leader cannot observe followers' actions or signals.

Definition 1 *A Perfect Bayesian Nash Equilibrium is given by*

- (i) *a strategy, or direction, for the organization a_L that maximizes $E[\Pi_L | \theta_L, S_L]$;*
- (ii) *a set of followers' actions $\{a_i\}_{i \in [0,1]}$ that maximize $E[\Pi_i | \theta_L, S_i]$.*

⁴Note that if we allow for costly information acquisition by the leader at date $t = 2$ then our model allows for an alternative interpretation than leader overconfidence. If the leader underinvests in information acquisition – as he would if he privately bears all the costs – and if this is observable (or anticipated) by followers when they act, then under-investment in second period information will have the same effect as overconfidence in our model: the leader will put more weight on the first signal.

Optimal actions We solve the model by backwards induction. When the leader chooses the organization's strategy a_L , the actions of the agents $\{a_i\}_{i \in [0,1]}$ are already determined. Since the first term of his payoff function (1) is zero, the leader's payoff in the final stage of the game reduces to $-E[(a_L - \theta)^2]$. The leader's optimal choice of strategy ex post then is to set a_L as close to the true state as possible: $a_L = E[\theta|\theta_L, S_L]$. According to Bayes' law, this expectation is

$$a_L = \lambda\theta_L + (1 - \lambda)S_L, \quad (2)$$

where the weight on the first signal is

$$\lambda := \sigma_p^{-2} / (\sigma_p^{-2} + \sigma_L^{-2}).$$

A rational leader (with $\sigma_p^2 = 1$) would set the weight λ equal to the relative precision of the first signal and the second: $1/(1 + \sigma_L^{-2})$.

Each follower takes the actions of the others as given and cannot influence the average action because he is of measure zero. Therefore, his objective function (1) reduces to $E[-(a_i - a_L)^2|\theta_L, S_i]$ and his optimal action a_i is equal to his expectation of the leader's action, given his own private signal S_i : $a_i = E[a_L|\theta_L, S_i]$. Again by Bayes' law the follower's belief is

$$a_i = E[a_L|\theta_L, S_i] = \lambda\theta_L + (1 - \lambda) [\phi\theta_L + (1 - \phi)S_i]. \quad (3)$$

The term in square brackets is the follower's expectation of the leader's signal $E[S_L|\theta_L, S_i]$. Since S_L is an independent, unbiased signal about θ , $E[S_L|\theta_L, S_i] = E[\theta|\theta_L, S_i]$. The expectation of θ is a precision-weighted sum of θ_L and S_i , where the weight on θ_L is

$$\phi := 1/(1 + \sigma_\theta^{-2}).$$

Optimal resoluteness. We define the organization's payoff Π (without subscript) as the integral over all followers' payoffs plus the leader's payoff, assuming that the leader along with all followers is of zero measure.⁵ The organization's ex-ante expected payoff therefore also has three components:

1. the variance of each follower's action around the leader's,

$$E[-(a_i - a_L)^2] = -(1 - \lambda)^2(\phi + \sigma_L^2)$$

2. the dispersion of followers' actions around the mean,

$$\int_j -(a_j - \bar{a})^2 dj = -(1 - \lambda)^2(1 - \phi)^2 \sigma_\theta^2$$

3. the distance of the leader's action from the true state,

$$E[-(a_L - \theta)^2] = -\lambda^2 - (1 - \lambda)^2 \sigma_L^2.$$

Summing the three terms and rearranging yields,

$$E\Pi = -(1 - \lambda)^2(\phi + 2\sigma_L^2 + \phi(1 - \phi)) - \lambda^2.$$

Recall that $\lambda := \sigma_p^{-2}/(\sigma_p^{-2} + \sigma_L^{-2})$ is a measure of the leader's resoluteness. The higher is λ the more resolute is the leader. Therefore a simple way of determining the effects of leader steadfastness on the organization's overall welfare is to differentiate the ex ante objective with respect to λ .

⁵Note that all our qualitative results survive even if the leader has non-zero weight but the optimal level of overconfidence may vary.

The partial derivative of the organization's ex-ante expected payoff with respect to λ is:

$$\frac{\partial E\Pi}{\partial \lambda} = 2(1 - \lambda)(\phi + 2\sigma_L^2 + \phi(1 - \phi)) - 2\lambda.$$

This is positive if

$$2\sigma_L^2 + \phi(2 - \phi) > \frac{\lambda}{1 - \lambda}.$$

With a rational leader we have $\sigma_p^2 = 1$, and therefore $\frac{\lambda}{1 - \lambda} = \sigma_L^2$. Thus, $\frac{\partial E\Pi}{\partial \lambda} > 0$ at $\frac{\lambda}{1 - \lambda} = \sigma_L^2$, so that some degree of resoluteness is always optimal. On the other hand, for an extremely stubborn leader who fails to update at all, $\lambda \rightarrow 1$ and the left side of the inequality approaches infinity, so that $\frac{\partial E\Pi}{\partial \lambda} < 0$. As $\frac{\lambda}{1 - \lambda}$ is continuous for $\lambda \in (0, 1)$, $\frac{\partial^2 E\Pi}{\partial \lambda^2} < 0$ and since the weight λ is strictly increasing in the perceived precision σ_p^{-2} , there exists an interior optimal level of resoluteness that maximizes the organization's expected payoff, which is given by

$$\sigma_p^{-2} = 2 + \phi(2 - \phi)\sigma_L^{-2}. \quad (4)$$

The 2 in Equation (4) is due to the fact that there are two reasons why resoluteness increases the expected payoff of the organization: First, steadfastness reduces the distance of the followers' actions from the leader's action $(a_i - a_L)^2$. Second, weighting the later signal less reduces the error in the leader's action that comes from the noise in S_L . Of course, there is a corresponding increase in the weight on the leader's prior that increases the error in the leader's action that comes from noise in θ_L . That effect is captured in the second term. The net effect of resoluteness is to increase the error in the leader's choice $(a_L - \theta)^2$.

We summarize this discussion in the proposition below.

Proposition 1 *The organization's ex-ante payoff is maximized with a leader's resoluteness level of $\sigma_p^{-2} = 2 + \phi(2 - \phi)\sigma_L^{-2} > 1$.*

In particular, since the second term in Equation (4) is always positive, it is strictly beneficial for an organization to have a *resolute* leader.

3.2 Strength of the mission statement

As the preceding analysis highlights, resoluteness of a leader provides a form of commitment to staying within the broad outlines of his mission. It ensures that the leader's strategy choice after learning new information does not deviate too much from the mission he set for the organization, which is centered on his prior belief. If the leader's beliefs do not change much, his strategy choice will be similar to his mission statement. This commitment in turn facilitates coordination. However, to the extent that leader resoluteness also introduces a bias in the organization's adaptation to the environment, it would seem that a more direct solution to the leader's time-consistency problem – allowing a rational leader to commit to staying the course – would be preferable. We explore this question in this section by introducing such a commitment device into our model. Specifically, we add the possibility for the leader to stake his or the organization's reputation on carrying through a proposed mission. Should the leader choose to deviate from the proposed course of action then the organization will incur an additional cost that is increasing in the distance between the initial mission statement and the final strategy. The higher is this cost, the stronger is the leader's mission statement.

An alternative interpretation of our commitment device is an incentive scheme for the leader, where the organization sets a punishment for deviating from the proposed mission (or a reward for carrying out a mission) that is increasing in the size of the deviation. It would seem that if the organization can incentivize a rational leader to optimally stay the course, then there is no longer any role for leader steadfastness.⁶

⁶The case where the organization sets the incentives is not identical to our model in which the leader chooses his own commitment cost. The on-line appendix shows that the alternative model delivers similar results.

We shall argue, however, that resoluteness is still valuable. The reason is that a leader does not commit as much as is socially optimal because some of the benefit of commitment comes from internalizing coordination externalities. As long as the leader does not appropriate this entire benefit, there will be too little commitment by a rational leader to staying the course.

In contrast, a resolute leader will also make commitments to staying the course, but such a leader will commit even more than a rational leader to sticking to a mission and thereby helps close the wedge between his marginal value of commitment and the socially optimal value. There are three differences between resoluteness and commitment:

1. Commitment is a choice the leader makes, not an immutable type,
2. Commitment has payoff consequences, and
3. Commitment cost (strength of the statement) is a more flexible policy instrument.

It could vary from project to project, while leader resoluteness is not malleable.

At the same time, there are similarities between resoluteness and commitment: comparative statics for commitment cost are the same as for resoluteness along almost every dimension.

Model extension. We add one additional choice to the model: The leader can choose a cost that he and the organization will incur that is increasing in the distance between his mission statement and the chosen strategy. We call this cost the *strength of a mission statement* and interpret it as being a reputational cost borne by the leader (and the organization).

The leader's payoff now has a new last term that captures the cost of lost reputation.

$$\Pi_L = -(a_i - a_L)^2 - \int_j (a_j - \bar{a})^2 dj - (a_L - \theta)^2 - c(a_L - \theta_L)^2. \quad (5)$$

The commitment cost c determines how big the quadratic loss is from having a final strategy far away from the initial mission statement.

Optimal actions. Given this payoff, the first order condition for the leader's action now yields:

$$a_L = \frac{1}{1+c} ((\lambda+c)\theta_L + (1-\lambda)S_L),$$

where $\lambda = \sigma_p^{-2}/(\sigma_p^{-2} + \sigma_L^{-2})$. As before, each follower chooses his action to match his expectation of the organization's strategy: $a_i = E[a_L|\theta_L, S_i]$. But follower expectations now take a different form:

$$a_i = \frac{1}{1+c} \{[\lambda+c+(1-\lambda)\phi]\theta_L + (1-\lambda)(1-\phi)S_i\}.$$

Given that all members' actions vary with the reputation cost c , it is natural to ask what payoff the organization could achieve if the reputation cost parameter c was chosen optimally. Alternatively, the optimal choice of c could also be interpreted as an optimal incentive scheme.

Thus consider the leader's choice of cost parameter c to maximize his own ex-ante expected payoff:

$$\max_c E\Pi_L = -\left(\frac{1-\lambda}{1+c}\right)^2 [c\sigma_p^2 + (1+c)\sigma_L^2 + (1-\phi)^2\sigma_\theta^2] - \left(\frac{\lambda+c}{1+c}\right)^2 \sigma_p^2.$$

Note that the expectation is taken given the leader's distorted beliefs about the precision of the initial signal, σ_p^{-2} . A stronger mission statement (higher c) shows up in the leader's expected utility in a way similar to a lower σ_p^2 . Both increase the weight the leader puts on the first signal, relative to the second.

The cost that maximizes this payoff is

$$c_L^* = \max \left\{ \frac{2\phi(1-\phi)}{\sigma_p^2 + \sigma_L^2} - 1, 0 \right\}. \quad (6)$$

The intuition here is that if followers have perfect information $\sigma_\theta^2 = 0$ ($\phi = 0$), there is no role for a commitment of the leader to stay the course, as followers are able to coordinate their actions independently of the leader. The -1 term in (6) arises because the leader expects to make some changes in the organization's strategy away from the initial mission statement and therefore wants to keep the cost of these changes small by choosing a low c . Note also that it is possible for the optimal reputation cost to be negative $c_L^* < 0$. One might interpret this as *commitment to reform*. In the results that follow, we consider choices of $c > 0$.

Lemma 1 *A more resolute leader chooses a higher commitment cost.*

Proof. $\partial c_L^* / \partial \sigma_p^2 = -2(1-\phi)^2 \sigma_\theta^2 / (\sigma_p^2 + \sigma_L^2)^2$. Since the numerator and denominator terms are both squares and the fraction is multiplied by -2 , it must be negative. Since more resoluteness is defined as a lower σ_p , and $\partial c_L^* / \partial \sigma_p^2 < 0$, the commitment cost is increasing in resoluteness. ■

Resolute leaders choose higher commitment costs because they believe that the probability of taking an action far away from their mission statement is low. They systematically underestimate the cost they will pay.

Optimal resoluteness. The organization's payoff is the same as before, with the added reputation cost term $-c(a_L - \theta_L)^2$. A resolute leader now affects the organization in two ways: through the weight λ put on the prior belief and through the chosen commitment cost c . The following equation sets the partial derivative $\frac{\partial E\Pi}{\partial \sigma_p^2}$ to zero, and

thus implicitly determines the optimal degree of resoluteness:

$$\left(\frac{\sigma_p^2}{2\phi^2(1-\phi)^2}\right) \left[-\sigma_L^2 - \phi(2-\phi) - \left(\frac{\sigma_L^2}{\sigma_p^2 + \sigma_L^2} + 1\right) \frac{\phi(1-\phi)(1+\sigma_L^2)}{\sigma_p^2 + \sigma_L^2}\right] + \frac{1}{\phi(1-\phi)} = 0.$$

Proposition 2 *Even with a commitment device which allows the leader to vary the strength of his mission statement, it is still optimal to choose a resolute leader. However, the level of resoluteness is lower than when $c = 0$.*

The proof can be found in the Appendix.

There are two reasons that the organization prefers a resolute leader to a rational, committed leader. The first reason comes from the difference between the organization's and the leader's payoffs. Since the alignment cost $(a_i - a_L)^2$ is always zero for the leader and is positive for the organization, rational leaders will choose a lower commitment cost than the organization would. Resolute leaders choose higher commitment costs and thus reconcile this difference in objectives. Of course, another solution to this problem would be to have the organization, rather than the leader, choose c .

The second benefit is that a resolute leader is more committed. Although he pledges to pay a higher cost for deviating from his initial announcement, he deviates less and thus incurs less of this cost. Both commitment and resoluteness entail costs: Commitment affects payoffs directly, while resoluteness worsens adaptation. Because both costs are convex, the lowest-cost solution is one that incurs some of each. The ideal leader exhibits some resoluteness and incurs some commitment cost.

3.3 Can optimal contracts replace resoluteness?

The reader may wonder if the need for a resolute leader is due to the fact that both the leader's and the followers' incentive schemes are imperfect. This intuition is correct. For the leader, if the organization can impose a reputation cost that is contingent on the realized signal S_L , then the organization can maximize their payoff with a rational

leader. The organization can impose no reputation cost on the leader for taking the first-best action and impose a very large negative reputation cost for taking any other action. In this manner, they can effectively take the choice of action away from the leader and make his preferences irrelevant. However, whenever the signal S_L is private information to the leader, or is not verifiable, a signal-contingent scheme is not possible and an incentive-compatible contract may be more costly than resoluteness, just like the commitment cost. Similarly, a leader with just the right preference for organizational inertia may take the optimal action, but such a leader may not exist.

For the followers, an optimal contract that rewarded coordination could, in theory, resolve the coordination problem that is the rationale for a resolute leader. In practice, getting followers to internalize the benefits of coordination is challenging because contracts cannot control followers' options outside the firm. Suppose that if followers take an action that is less coordinated, but closer to the true state, they can get a better job offer from another firm. For example, this action could be investing in skills related to a technology that ultimately gets adopted. Then, despite a firm contract that rewards being a team player, the followers might not coordinate as much as they should. Therefore, since a firm cannot prevent a worker from leaving, an optimal contract may not be able to fully resolve the coordination problem.

This highlights that while resoluteness alleviates the time-consistency problem, it does not perfectly resolve it. Yet, realistic information frictions or outside options may render infeasible the kinds of first-best contracts that obviate the benefits of resoluteness.

4 Lead by being led

In this section, not only do followers learn from their leader (top-down information flow), leaders also learn from followers (bottom-up information flow). We replace the exogenous signal S_L with an endogenous signal, which is the average action of the

followers, plus some noise. Our main conclusion is that this moderates the benefit of resoluteness. A leader who is very stubborn dissuades his followers from acting based on their private information and suppresses information revelation. Because the leader's action depends on what he learns from agents' actions, which in turn depend on what agents expect the leader to do, multiple equilibria arise.

4.1 Merits and drawbacks of resoluteness

The payoff functions are as before (but with the commitment costs removed). Therefore, the leader's and followers' first order conditions are the same as in (2). Followers also form expectations over the state as before. However, now followers' actions aggregate into the signal for the leader, which is the publicly observable organization output A :

$$A = \int_j a_j dj + e,$$

where e is the independent noise term: $e \sim \mathcal{N}(0, \sigma_e^2)$. As before, the leader uses the signal A to update his prior belief θ_L and make a final inference about θ . Suppose that followers' equilibrium strategies take the form

$$a_i(S_i) = \beta S_i + (1 - \beta)\theta_L, \tag{7}$$

then we can rewrite the aggregate output signal as

$$\hat{S}_L := \frac{1}{\beta} [A - (1 - \beta)\theta_L] = \theta + \frac{1}{\beta}e.$$

Note that this signal's precision is given by $\beta^2 \sigma_e^{-2}$. Thus, the more followers rely on their private information (the higher is β), the more accurate this signal becomes. Of course, if followers rely more on their private signals S_i there is also less coordination among them. Thus, in this setting coordinated actions have both a positive payoff

externality and a negative information externality because they suppress information revelation to the leader.

Optimal actions As in Section 3.1, the leader's optimal action is

$$a_L = E[\theta|\theta_L, \hat{S}_L] = \lambda\theta_L + (1 - \lambda)\hat{S}_L. \quad (8)$$

But now

$$\lambda = \frac{\sigma_p^{-2}}{\sigma_p^{-2} + \beta^2 \sigma_e^{-2}}, \quad (9)$$

where β is chosen by the followers and will depend on the leader's resoluteness σ_p^{-2} .

As before, each follower's optimal action is their forecast of the leader's action:

$$a_i(S_i) = E[a_L|\theta_L, S_i] = \lambda\theta_L + (1 - \lambda)(\phi\theta_L + (1 - \phi)S_i). \quad (10)$$

Note that this is linear in θ_L and S_i , which validates the conjecture in (7). Matching coefficients reveals that the weight followers place on their private signal is:

$$\beta = (1 - \lambda)(1 - \phi). \quad (11)$$

Thus, the only difference in this new setting is that now λ depends on β and conversely β depends on λ . Therefore, to solve for the equilibrium actions we need to solve the fixed point problem given by the equations (9) and (11).

Substituting for λ in equation (11) delivers a third-order polynomial in β

$$\beta^3 - (1 - \phi)\beta^2 + \sigma_p^{-2}\sigma_e^2\beta = 0.$$

This equation has three potential solutions: (i) a “dictatorial equilibrium” character-

ized by $\beta = 0$, $\lambda = 1$; and (ii) two “lead by being led equilibria” with

$$\beta = \frac{1}{2} \left[(1 - \phi) \pm \sqrt{(1 - \phi)^2 - 4\sigma_p^{-2}\sigma_e^2} \right]. \quad (12)$$

Since we focus on stable equilibria we neglect the unstable equilibrium with the smaller quadratic root for β . Note that while the dictatorial equilibrium exists for any set of parameter values, the “lead by being led equilibrium” only exists for

$$(1 - \phi)^2 > 4\sigma_e^2\sigma_p^{-2}. \quad (13)$$

Proposition 3 *When leaders learn from followers’ actions, there are two stable (linear) equilibria:*

- (i) A **dictatorial equilibrium** where there is perfect coordination $a_i = a_L = \theta_L$, but information flow from followers to leaders is totally suppressed.
- (ii) A **“lead-by-being-led equilibrium”** where coordination is reduced, but the organization is better adapted to the environment, as it relies on more information to determine its strategy:

$$a_i = \beta S_i + (1 - \beta)\theta_L \quad \text{where} \quad \beta = \frac{1}{2} \left[(1 - \phi) + \sqrt{(1 - \phi)^2 - 4\sigma_p^{-2}\sigma_e^2} \right],$$

and

$$a_L = E[\theta | \theta_L, \hat{S}_L] = \lambda \theta_L + (1 - \lambda) \hat{S}_L \quad \text{where} \quad \lambda = \frac{1}{2} \left[1 + \sqrt{1 - 4\sigma_e^2\sigma_p^{-2}(1 - \phi)^{-2}} \right]$$

The logic of the multiple equilibria is the following: If followers expect leaders to learn no new information from their actions, then they expect the leader’s action to be the same as his initial announcement ($a_L = \theta_L$). Since agents want to take actions close to the leader’s action, they choose the same action $a_i = \theta_L$. But when agents all take the same actions, they reveal no new information. So, their expectation is self-

confirming. In contrast, when followers expect the leader to learn new information, they try to forecast what he will learn, using their private signals. Because their actions are based on this forecast and on their private signals, aggregate output reveals information. So, the expectation that the leader will learn is also confirmed.

Corporate culture One way of interpreting the multiplicity of equilibria in this setting is that the role of leadership in an organization must be adapted to the organization's *culture*. In a dictatorial organization, where followers are expected to just coordinate around the leader's mission statement it is best to have a rational, well-informed, and competent leader. In contrast, and somewhat counter-intuitively, in a democratic organization, where followers are expected to take a lot of *initiatives* and where the leader learns from the followers' actions, it may nevertheless be best to have a somewhat resolute leader. This is especially valuable if the more competent leader has significantly more precise priors about the environment than the information of other members of the organization.

Optimal resoluteness In the dictatorial equilibrium (where $\beta = 0$, $\lambda = 1$), leader resoluteness has no effect on the organization's ex-ante expected payoff because it only works through the coefficients β and λ which, in this case, do not depend on the leader's resoluteness.

In the stable lead-by-being-led equilibrium, the organization's expected payoff is

$$E\Pi = -(1 - \lambda)^2(2\beta^{-2}\sigma_e^2 + \phi(2 - \phi)) - \lambda^2.$$

Taking the derivative with respect to leader's resoluteness, yields

$$\frac{\partial E\Pi}{\partial \sigma_p^2} = -[2(1 - \lambda)\phi(2 - \phi) - 2\lambda] \frac{-\sigma_L^2}{(\sigma_L^2 + \sigma_p^2)^2}. \quad (14)$$

Leader resoluteness is optimal if the partial derivative $\frac{\partial E\Pi}{\partial \sigma_p^2}$ is negative at $\sigma_p^2 = 1$.

Proposition 4 *In the lead-by-being-led equilibrium, leader resoluteness increases the organization's expected payoff if and only if*

$$\beta^{-2}\sigma_e^2 < \phi(2 - \phi). \quad (15)$$

Otherwise, the opposite of resoluteness, "indecisiveness" increases the expected payoff.

When is the leader's resoluteness beneficial? There are situations where the leader is already extracting most of the relevant information about the environment θ . If the signal the leader sees from the followers' output is already very precise (low $\beta^{-2}\sigma_e^2$), then the benefit of better coordination ($\phi(2 - \phi)$) matters more than the marginal loss of signal quality. When the leader learns little from followers' actions (σ_e^2/β^2 is large), resoluteness worsens this problem. Indecisiveness then allows the leader to observe more precise information and take a better-directed final action.

Setting (14) equal to zero gives the optimal degree of resoluteness, as long as the learning equilibrium exists (13) and the second-order condition holds. The existence condition is likely to be satisfied if the noise in output, the degree of leader resoluteness, and the true precision of the leader's prior are low, and the precision of agents' private information is high. In sum, resoluteness is most valuable when there is little noise in output and the true variance of the leader's prior is high. In these situations, the risk that the leader's resoluteness will suppress followers' information and possibly lead to a maladapted final action for the organization, are minimized. Note finally that the effect of changes in information quality of followers' signals on the value of leader resoluteness for the organization is ambiguous.

4.2 Can resoluteness be preferable to competence?

Our solution has another surprising implication. So far we have fixed σ_1^2 , the true variance of θ_L , to be equal to one. But, allowing for different values of σ_1^2 is a simple way of introducing differences in a leader's *competence* into our model. A highly competent leader then would be one who has a highly accurate prior θ_L , that is someone with a low value of σ_1^2 .

Intuitively, one expects greater competence of a leader to be an unreserved benefit for an organization. A leader with a more accurate prior, would make better decisions other things equal, and this can only benefit the organization. As it turns out, however, greater competence of a leader in our model may also have a *side effect*: it may crowd out learning from the actions of followers. If the leader's prior is too precise he may no longer be able to learn anything from the actions of the followers, as the latter decide to ignore their own information when choosing their actions. The question then arises in our model whether it may be preferable for the organization to have a resolute leader who knows less, but who is also able to learn from followers.

We provide a set of conditions below on the parameters of the model such that the organization is better off with a resolute leader rather than a (possibly more competent) rational leader. Such a situation may arise when it is better for the organization if the leader learns from the actions of followers, and when only the resolute leader is able to do so in equilibrium.

Observe first that when σ_1^2 varies, the resolute leader's optimal action is unaffected as the leader believes the variance to be σ_p^2 . Thus, a_L is determined by (8) and (9). The followers' actions are affected because when the true precision of the leader's announcement σ_0^{-2} changes, the weight followers put on that announcement when forming expectations of the state becomes $\phi = \sigma_0^{-2}/(\sigma_0^{-2} + \sigma_\theta^{-2})$. Given this new definition of ϕ , the followers announcements take the same form as before (10). Since both leaders' and followers' actions take the same form as before, the solution is (12) and the lead-

by-being-lead equilibrium exists whenever (13) holds. In sum, changing competence only affects the solution through its effect on the value of ϕ .

Proposition 5 *Suppose there are two managers, one resolute and one rational. Both have initial beliefs with the same perceived precision $\sigma_p^{-2} = \sigma_0^{-2}$, but the resolute manager's beliefs have lower true precision $\underline{\sigma_0^{-2}} < \sigma_0^{-2}$. If*

$$\left(\frac{\sigma_\theta^{-2}}{\underline{\sigma_0^{-2}} + \sigma_\theta^{-2}}\right)^2 \geq 4\sigma_e^2\sigma_p^{-2} \quad (16)$$

and

$$\left(\frac{\sigma_\theta^{-2}}{\sigma_0^{-2} + \sigma_\theta^{-2}}\right)^2 \leq 4\sigma_e^2\sigma_0^{-2}, \quad (17)$$

then the rational, more competent leader always ends up in the dictatorial equilibrium, while with the resolute, but less competent leader can end up in a lead-by-being-led equilibrium. The dictatorial equilibrium is worse for the organization if

$$\sigma_0^2 > (1 - \lambda)^2(\phi\sigma_0^2 + 2\beta^{-2}\sigma_e^2 + (1 - \phi)^2\sigma_\theta^2) + \lambda^2\underline{\sigma_0^{-2}}. \quad (18)$$

Thus, when (16), (17) and (18) hold, the resolute leader is preferred to the more competent but rational leader.

Proof. Under condition (17) only a dictatorial equilibrium exists with a rational leader with $\lambda = 1$ and $\beta = 0$. And under condition (16) a lead-by-being-led equilibrium may exist with a resolute leader with precision σ_p^{-2} . With the resolute leader, the three components of the organization's objective function are first,

$$E[-(a_i - a_L)^2] = -(1 - \lambda)^2(\phi\underline{\sigma_0^{-2}} + \sigma_L^2),$$

second,

$$\int_j -(a_j - \bar{a})^2 dj = -(1 - \lambda)^2(1 - \phi)^2\sigma_\theta^2,$$

and third,

$$E[-(a_L - \theta)^2] = -\lambda^2 \underline{\sigma_0^{-2}} - (1 - \lambda)^2 \sigma_L^2.$$

Adding these three terms and rearranging yields,

$$E\Pi = -(1 - \lambda)^2 (\phi \underline{\sigma_0^{-2}} + 2\beta^{-2} \sigma_e^2 + (1 - \phi)^2 \sigma_\theta^2) - \lambda^2 \underline{\sigma_0^{-2}}.$$

In the dictatorial equilibrium, $\lambda = 1$, and $E\Pi = -\sigma_0^2$. Thus, the dictatorial equilibrium is worse for the organization if condition (18) holds. ■

In light of the proposition it is possible for the organization to prefer a less competent but resolute leader to a more competent but rational leader as long as the difference in competence is not too large and the leader's steadfastness is large enough. The basic logic behind the proposition is that a more precise prior (a higher σ_1^{-2}) induces both the rational leader and the followers to weight the mission statement more when forming their forecasts. When followers weight the mission statement more, they weight their idiosyncratic information less. This makes their aggregate output less informative about the environment, which encourages the leader to put even less weight on the information in output. This feedback, in turn, can result in a breakdown of the lead-by-being-led equilibrium. As a result a less competent but more resolute leader can welfare-dominate a more competent, rational leader who gets stuck in a dictatorial equilibrium.⁷

5 Conclusion

We have proposed a model of leadership in organizations that captures a fundamental tension between adaptation to changing circumstances and coordination of followers on a given course of action. Specifically, the leader's problem is to steer the organization

⁷It is worth mentioning that for a less competent leaders it might be optimal to act resolute in order to appear as competent, as in Prendergast and Stole (1996).

towards the best overall strategy or mission, while communicating a clear mission to other organization members that helps them coordinate and implement the organization's strategy. We have stripped down our model of leadership to five main phases. In a first phase, the leader assesses the environment and defines a mission for the organization. In a second phase, the other members attempt to coordinate around the leader's stated mission. Followers face their own dilemma, as they are aware that the leader may change the organization's strategy in a subsequent stage in light of new information he gets about the environment. Therefore, they will use their own private information to forecast the likely change in strategy. Since private information is heterogeneous, forecasts and resulting actions are heterogeneous. This is the coordination problem that the leader is trying to minimize. In a third phase, the leader gets new information, updates his assessment of the state and chooses a direction for the organization. Fourth and last, the state is revealed and leader's and followers' payoffs are realized.

The main message of the paper is that the tension between coordination and adaptation creates a time-consistency problem. This problem is ameliorated when leaders are resolute. Steadfastness causes the leader to stick to his guns because he fails to update as much as he rationally should. Even when the leader can pledge a commitment cost, being resolute is helpful for two reasons: First, it induces the leader to make a stronger commitment not to change the organization's direction. The stronger commitment achieves better coordination. Second, resoluteness results in lower commitment costs paid because the resolute leader makes smaller changes in direction. The model also illustrates the dangers of resoluteness in situations where followers have valuable information. Resolute leaders are less likely to learn what their followers know and may therefore lead their organization in the wrong direction.

A Technical Appendix

A.1 Results: Basic Model

The organization's ex-ante expected payoff has three components:

1. the variance of each follower's action around the leader's,

$$\begin{aligned} E[-(a_i - a_L)^2] &= E[-(\lambda\theta_L + (1-\lambda)[\phi\theta_L + (1-\phi)S_i] - \lambda\theta_L - (1-\lambda)S_L)^2] \\ &= E[-((1-\lambda)[\phi\theta_L + (1-\phi)S_i] - (1-\lambda)S_L)^2] \end{aligned}$$

Since θ_L, S_i, S_L each have independent signal noise, and the coefficients in the previous expression add up to zero, we can subtract the true θ from each one and then have independent, mean-zero variables that we can take expectations of separately. The first term $\phi\theta_L + (1-\phi)S_i - \theta$ is the posterior belief error of the follower. It has precision that is the sum of the signal precisions $(1 + \sigma_\theta^{-2})$ and therefore has variance $1/1 + \sigma_\theta^{-2} = \phi$. In the second term, $S_L - y$ has variance σ_L^2 . Therefore, expected utility is

$$\begin{aligned} E[-(a_i - a_L)^2] &= -(1-\lambda)^2\phi - (1-\lambda)^2\sigma_L^2 \\ &= -(1-\lambda)^2(\phi + \sigma_L^2) \end{aligned}$$

But in the leader's utility, he sets this term =0 because $i=L$.

2. the dispersion of followers' actions around the mean,

$$\begin{aligned} \int_j -(a_j - \bar{a})^2 dj &= -E[(\lambda\theta_L + (1-\lambda)[\phi\theta_L + (1-\phi)S_i] - \lambda\theta_L - (1-\lambda)[\phi\theta_L + (1-\phi)\theta])^2] \\ &= -E[(1-\lambda)(1-\phi)S_i + (1-\lambda)(1-\phi)\theta]^2 \\ &= -(1-\lambda)^2(1-\phi)^2\sigma_\theta^2 \end{aligned}$$

Since the first signal cancels out here, this expectation is the same for the leader and the organization.

3. the distance of the leader's action from the true state,

$$\begin{aligned}
E[-(a_L - \theta)^2] &= -E[(\lambda\theta_L + (1 - \lambda)S_L - \theta)^2] \\
&= -\lambda^2 E[(\theta_L - \theta)^2] + (1 - \lambda)^2 E[(S_L - \theta)^2] \\
&= -\lambda^2 - (1 - \lambda)^2 \sigma_L^2.
\end{aligned}$$

The leader believes that this is

$$E^P[-(a_L - \theta)^2] = -\lambda^2 \sigma_p^2 - (1 - \lambda)^2 \sigma_L^2$$

Organization's expected utility Summing the three terms and rearranging yields,

$$\begin{aligned}
E\Pi &= -(1 - \lambda)^2 \phi - (1 - \lambda)^2 \sigma_L^2 - (1 - \lambda)^2 (1 - \phi)^2 \sigma_\theta^2 - \lambda^2 - (1 - \lambda)^2 \sigma_L^2. \\
E\Pi &= -(1 - \lambda)^2 (\phi + 2\sigma_L^2 + (1 - \phi)^2 \sigma_\theta^2) - \lambda^2.
\end{aligned}$$

while the expression in the paper was $. = -[(1 - \lambda)^2 (2\sigma_L^2 + ((1 - \phi)^2 + \phi)\sigma_\theta^2) + \lambda^2]$.

The partial derivative of the organization ex-ante expected payoff with respect to λ is:

$$\frac{\partial E\Pi}{\partial \lambda} = 2(1 - \lambda)(\phi + 2\sigma_L^2 + (1 - \phi)^2 \sigma_\theta^2) - 2\lambda.$$

This is positive if

$$\begin{aligned}
2(1 - \lambda)(\phi + 2\sigma_L^2 + (1 - \phi)^2 \sigma_\theta^2) &> 2\lambda \\
\phi + 2\sigma_L^2 + (1 - \phi)^2 \sigma_\theta^2 &> \frac{\lambda}{1 - \lambda}.
\end{aligned}$$

With a rational leader we have $\sigma_p^2 = 1$, and therefore $\frac{\lambda}{1 - \lambda} = \sigma_L^2$. Thus, $\frac{\partial E\Pi}{\partial \lambda} > 0$ at $\frac{\lambda}{1 - \lambda} = \sigma_L^2$, so that some degree of resoluteness is always optimal. On the other hand, for an extremely resolute leader who fails to update at all, $\lambda \rightarrow 1$, and the left side of the inequality approaches infinity, so that $\frac{\partial E\Pi}{\partial \lambda} < 0$. As $\frac{\lambda}{1 - \lambda}$ is continuous for $\lambda \in (0, 1)$, $\frac{\partial^2 E\Pi}{\partial \lambda^2} < 0$ and since the weight λ is strictly increasing in the perceived precision σ_p^{-2} , there exists an interior optimal level of resoluteness that maximizes

the organization's expected payoff, which is given by

$$\phi + 2\sigma_L^2 + (1 - \phi)^2\sigma_\theta^2 = \frac{\sigma_L^2}{\sigma_p^2}. \quad (19)$$

$$\sigma_p^{-2} = 2 + \phi\sigma_L^{-2} + (1 - \phi)^2\sigma_\theta^2\sigma_L^{-2} \quad (20)$$

$$\sigma_p^{-2} = 2 + \phi\sigma_L^{-2} + \phi(1 - \phi)\sigma_L^{-2} \quad (21)$$

$$\sigma_p^{-2} = 2 + \phi(2 - \phi)\sigma_L^{-2} \quad (22)$$

This proves proposition 1.

A.2 Results: Resoluteness and Commitment

The leader's utility now has a new last term that captures the cost of commitment.

$$\Pi_L = - \int_j (a_j - \bar{a})^2 dj - (a_L - \theta)^2 - c(a_L - \theta_L)^2. \quad (23)$$

The commitment cost c determines how big the quadratic loss is from having a final action far away from the initial announcement. Given this utility, the first order condition for the leader's action yields

$$\begin{aligned} -2(a_L - E[\theta]) - 2c(a_L - \theta_L) &= 0 \\ (1 + c)a_L - E[\theta] - c\theta_L &= 0 \\ (1 + c)a_L &= \lambda\theta_L + (1 - \lambda)S_L + c\theta_L \\ a_L &= \frac{1}{1 + c} ((\lambda + c)\theta_L + (1 - \lambda)S_L), \end{aligned}$$

where $\lambda = \sigma_p^{-2}/(\sigma_p^{-2} + \sigma_L^{-2})$. As before, each follower chooses his action to match its expectation of the organization's strategy: $a_i = E[a_L|\theta_L, S_i]$. But follower expectations now take a different form:

$$\begin{aligned} a_i &= \frac{1}{1 + c} ((\lambda + c)\theta_L + (1 - \lambda)E[S_L|\theta_L, S_i]) \\ &= \frac{1}{1 + c} ((\lambda + c)\theta_L + (1 - \lambda)(\phi\theta_L + (1 - \phi)S_i)) \\ &= \frac{1}{1 + c} \{[\lambda + c + (1 - \lambda)\phi]\theta_L + (1 - \lambda)(1 - \phi)S_i\} \end{aligned}$$

The organization's ex-ante expected payoff now has 4 components

1. the variance of each follower's action around the leader's,

$$\begin{aligned} E[-(a_i - a_L)^2] &= E\left[-\left(\frac{1}{1+c}((\lambda+c)\theta_L + (1-\lambda)S_L) - \frac{1}{1+c}\{[\lambda+c+(1-\lambda)\phi]\theta_L + (1-\lambda)(1-\phi)S_i\}\right)^2\right] \\ &= -\left(\frac{1}{1+c}\right)^2 E[(1-\lambda)S_L - (1-\lambda)(\phi\theta_L - (1-\phi)S_i)]^2 \end{aligned}$$

Since θ_L, S_i, S_L each have independent signal noise, and the coefficients in the previous expression add up to zero, we can subtract the true θ from each one and then have independent, mean-zero variables that we can take expectations of separately. The second term $\phi\theta_L + (1-\phi)S_i - \theta$ is the posterior belief error of the follower. As before, it has precision that is the sum of the signal precisions and therefore has variance $1/1 + \sigma_\theta^{-2} = \phi$. In the second term, $S_L - y$ has variance σ_L^2 . Therefore, expected utility is

$$E[-(a_i - a_L)^2] = -\left(\frac{1}{1+c}\right)^2 (1-\lambda)^2 (\phi + \sigma_L^2)$$

For the leader, this component of utility is zero.

2. the dispersion of followers' actions around the mean,

$$\begin{aligned} \int_j -(a_j - \bar{a})^2 dj &= -\left(\frac{1}{1+c}\right)^2 E[[\lambda+c+(1-\lambda)\phi]\theta_L + (1-\lambda)(1-\phi)S_i \\ &\quad - [\lambda+c+(1-\lambda)\phi]\theta_L + (1-\lambda)(1-\phi)\theta]^2] \\ &= -\left(\frac{1}{1+c}\right)^2 E[(1-\lambda)^2(1-\phi)^2(S_i - \theta)^2] \\ &= -\left(\frac{1}{1+c}\right)^2 (1-\lambda)^2(1-\phi)^2\sigma_\theta^2 \end{aligned}$$

The leader and the organization have the same perceived utility from this component because the first signal drops out.

3. the distance of the leader's action from the true state,

$$\begin{aligned}
E[-(a_L - \theta)^2] &= -E\left[\left(\frac{1}{1+c}\right)((\lambda+c)\theta_L + (1-\lambda)S_L) - \theta\right]^2 \\
&= -\left(\frac{\lambda+c}{1+c}\right)^2 E[(\theta_L - \theta)^2] + \left(\frac{1-\lambda}{1+c}\right)^2 E[(S_L - \theta)^2] \\
&= -\left(\frac{\lambda+c}{1+c}\right)^2 - \left(\frac{1-\lambda}{1+c}\right)^2 \sigma_L^2.
\end{aligned}$$

The leader believes that this component is

$$E^P[-(a_L - \theta)^2] = -\left(\frac{\lambda+c}{1+c}\right)^2 \sigma_p^2 - \left(\frac{1-\lambda}{1+c}\right)^2 \sigma_L^2.$$

4. Finally, expected utility depends on the commitment cost incurred.

$$\begin{aligned}
-c(a_L - \theta_L)^2 &= -c\left(\frac{1}{1+c}\left((\lambda+c)\theta_L + (1-\lambda)S_L\right) - \theta_L\right)^2 \\
&= -c\left(\frac{1-\lambda}{1+c}\right)^2 (S_L - \theta_L)^2 \\
-E[c(a_L - \theta_L)^2] &= -c\left(\frac{1-\lambda}{1+c}\right)^2 (1 + \sigma_L^2)
\end{aligned}$$

The leader believes that this will be

$$-E^P[c(a_L - \theta_L)^2] = c\left(\frac{1-\lambda}{1+c}\right)^2 (\sigma_p^2 + \sigma_L^2)$$

Organization's expected utility Summing the three terms and rearranging yields the expected utility under the objective probability measure,

$$\begin{aligned}
E\Pi &= -\left(\frac{1-\lambda}{1+c}\right)^2 (\phi + \sigma_L^2) - \left(\frac{1-\lambda}{1+c}\right)^2 (1-\phi)^2 \sigma_\theta^2 - \left(\frac{\lambda+c}{1+c}\right)^2 - \left(\frac{1-\lambda}{1+c}\right)^2 \sigma_L^2 - c\left(\frac{1-\lambda}{1+c}\right)^2 (1 + \sigma_L^2). \\
&= -\left(\frac{1-\lambda}{1+c}\right)^2 [c + \phi + (2+c)\sigma_L^2 + (1-\phi)^2 \sigma_\theta^2] - \left(\frac{\lambda+c}{1+c}\right)^2
\end{aligned}$$

Leader's expected utility But for the leader who has distorted beliefs, $(\theta_L - \theta)^2 = \sigma_p^2$. Because the leader understands that the followers do not believe the same that he believes, this does not change ϕ . It changes only the third and fourth terms. Furthermore, the leader gets no adverse utility

consequences from his utility being far away from itself, so the first term is zero. That makes the leader's expected utility

$$E\Pi_L = - \left(\frac{1-\lambda}{1+c} \right)^2 [c\sigma_p^2 + (1+c)\sigma_L^2 + (1-\phi)^2\sigma_\theta^2] - \left(\frac{\lambda+c}{1+c} \right)^2 \sigma_p^2$$

The leader chooses his strength of commitment c to maximize this expected utility. The first order condition is

$$\begin{aligned} 2(1+c)^{-3} \left((1-\lambda)^2(c\sigma_p^2 + (1+c)\sigma_L^2 + (1-\phi)^2\sigma_\theta^2) + (\lambda+c)^2\sigma_p^2 \right) - \left(\frac{1-\lambda}{1+c} \right)^2 (\sigma_p^2 + \sigma_L^2) - \frac{2(\lambda+c)}{(1+c)^2}\sigma_p^2 &= 0 \\ (1-\lambda)^2(2c\sigma_p^2 + 2(1+c)\sigma_L^2 + 2(1-\phi)^2\sigma_\theta^2 - (1+c)(\sigma_p^2 + \sigma_L^2)) + (\lambda+c)^2 2\sigma_p^2 - 2(\lambda+c)(1+c)\sigma_p^2 &= 0 \\ (1-\lambda)^2((c-1)\sigma_p^2 + (1+c)\sigma_L^2 + 2(1-\phi)^2\sigma_\theta^2) - 2(\lambda+c)(1-\lambda)\sigma_p^2 &= 0 \\ c((1-\lambda)(\sigma_p^2 + \sigma_L^2) - 2\sigma_p^2) + (1-\lambda)(-\sigma_p^2 + \sigma_L^2 + 2(1-\phi)^2\sigma_\theta^2) - 2\lambda\sigma_p^2 &= 0 \end{aligned}$$

Note that $(1-\phi)^2\sigma_\theta^2 = \sigma_\theta^{-2}/(1+\sigma_\theta^{-2})^2 = \phi(1-\phi)$.

$$c((1-\lambda)\sigma_L^2 - (1+\lambda)2\sigma_p^2) = (1-\lambda)(-\sigma_L^2 - 2\phi(1-\phi)) + (1+\lambda)\sigma_p^2$$

Note that the second order condition is

$$(1-\lambda)(\sigma_p^2 + \sigma_L^2) - 2\sigma_p^2 < 0$$

In other words, in order for the first-order condition to characterize an optimum, it needs to be that

$$\begin{aligned} (1-\lambda)\sigma_L^2 &< (2-(1-\lambda))\sigma_p^2 \\ (1-\lambda)\sigma_L^2 &< (1+\lambda)\sigma_p^2 \end{aligned}$$

If the second-order condition holds, the utility-maximizing commitment is

$$\begin{aligned} c &= \frac{2(1-\lambda)\phi(1-\phi)}{(1+\lambda)\sigma_p^2 - (1-\lambda)\sigma_L^2} - 1 \\ &= \frac{2\phi(1-\phi)}{\sigma_L^2 + \sigma_p^2} - 1 \end{aligned}$$

Lemma 1: The partial derivative of c with respect to σ_p^2 is

$$\frac{\partial c_L^*}{\partial \sigma_p^2} = \frac{-2\phi(1-\phi)}{(\sigma_L^2 + \sigma_p^2)^2}$$

Since $\phi < 1$, this expression is always negative. Since more resoluteness means lower σ_p^2 , more resoluteness increases the optimal c for the leader to choose.

Optimal resoluteness for the organization The next step is to determine the organization's expected utility, as a function of resoluteness. Substituting for c and λ in $E\Pi$ and noting that $\lambda = \sigma_L^2/(\sigma_p^2 + \sigma_L^2)$,

$$\begin{aligned} E\Pi &= -\left(\frac{\sigma_p^2}{2\phi(1-\phi)}\right)^2 \left[2\sigma_L^2 + \phi(2-\phi) + \left(\frac{2\phi(1-\phi)}{\sigma_p^2 + \sigma_L^2} - 1\right)(1 + \sigma_L^2)\right] - \left(\frac{\sigma_L^2 + 2\phi(1-\phi) - (\sigma_p^2 + \sigma_L^2)}{2\phi(1-\phi)}\right)^2 \\ &= -\left(\frac{\sigma_p^2}{2\phi(1-\phi)}\right)^2 \left[\sigma_L^2 + \phi(2-\phi) + \left(\frac{2\phi(1-\phi)}{\sigma_p^2 + \sigma_L^2}\right)(1 + \sigma_L^2) - 1\right] - \left(1 - \frac{\sigma_p^2}{2\phi(1-\phi)}\right)^2 \\ &= -\left(\frac{\sigma_p^2}{2\phi(1-\phi)}\right)^2 \left[\sigma_L^2 + \phi(2-\phi) + \left(\frac{2\phi(1-\phi)}{\sigma_p^2 + \sigma_L^2}\right)(1 + \sigma_L^2) - 1\right] - 1 + \frac{\sigma_p^2}{\phi(1-\phi)} - \left(\frac{\sigma_p^2}{2\phi(1-\phi)}\right)^2 \\ &= -\left(\frac{\sigma_p^2}{2\phi(1-\phi)}\right)^2 \left[\sigma_L^2 + \phi(2-\phi) + \left(\frac{2\phi(1-\phi)}{\sigma_p^2 + \sigma_L^2}\right)(1 + \sigma_L^2)\right] - 1 + \frac{\sigma_p^2}{\phi(1-\phi)} \end{aligned}$$

Then, take the partial derivative w.r.t. resoluteness to get its marginal utility.

$$\begin{aligned} \frac{\partial E\Pi}{\partial \sigma_p^2} &= -2\left(\frac{\sigma_p^2}{2\phi^2(1-\phi)^2}\right) \left[\sigma_L^2 + \phi(2-\phi) + \left(\frac{2\phi(1-\phi)}{\sigma_p^2 + \sigma_L^2}\right)(1 + \sigma_L^2)\right] - \left(\frac{\sigma_p^2}{2\phi(1-\phi)}\right)^2 \left[\frac{-2\phi(1-\phi)}{(\sigma_p^2 + \sigma_L^2)^2}(1 + \sigma_L^2)\right] \\ &\quad + \frac{1}{\phi(1-\phi)} \\ &= \left(\frac{\sigma_p^2}{2\phi^2(1-\phi)^2}\right) \left[-\sigma_L^2 - \phi(2-\phi) - \left(\frac{2\phi(1-\phi)}{\sigma_p^2 + \sigma_L^2}\right)(1 + \sigma_L^2) + \frac{\sigma_p^2\phi(1-\phi)}{(\sigma_p^2 + \sigma_L^2)^2}(1 + \sigma_L^2)\right] + \frac{1}{\phi(1-\phi)} \\ &= \left(\frac{\sigma_p^2}{2\phi^2(1-\phi)^2}\right) \left[-\sigma_L^2 - \phi(2-\phi) - \left(\frac{-\sigma_p^2}{\sigma_p^2 + \sigma_L^2} + 2\right) \frac{\phi(1-\phi)(1 + \sigma_L^2)}{\sigma_p^2 + \sigma_L^2}\right] + \frac{1}{\phi(1-\phi)} \\ &= \left(\frac{\sigma_p^2}{2\phi^2(1-\phi)^2}\right) \left[-\sigma_L^2 - \phi(2-\phi) - \left(\frac{\sigma_L^2}{\sigma_p^2 + \sigma_L^2} + 1\right) \frac{\phi(1-\phi)(1 + \sigma_L^2)}{\sigma_p^2 + \sigma_L^2}\right] + \frac{1}{\phi(1-\phi)} \end{aligned}$$

Finally, evaluate this at $\sigma_p^2 = 1$ to see if resoluteness is optimal.

$$\frac{\partial E\Pi}{\partial \sigma_p^2} \Big|_{\sigma_p=1} = \left(\frac{1}{2\phi^2(1-\phi)^2} \right) \left[-\sigma_L^2 - \phi(2-\phi) - \left(\frac{\sigma_L^2}{1+\sigma_L^2} + 1 \right) \frac{\phi(1-\phi)(1+\sigma_L^2)}{1+\sigma_L^2} + 2\phi(1-\phi) \right]$$

This is negative (meaning that some degree of resoluteness is optimal) if

$$\begin{aligned} -\sigma_L^2 - \phi(2-\phi) - \left(\frac{\sigma_L^2}{1+\sigma_L^2} + 1 \right) \frac{\phi(1-\phi)(1+\sigma_L^2)}{1+\sigma_L^2} + 2\phi(1-\phi) &< 0 \\ -\sigma_L^2 - \phi^2 - \phi(1-\phi) \left(\frac{\sigma_L^2}{1+\sigma_L^2} + 1 \right) &< 0 \\ -\sigma_L^2 - \phi + \phi(1-\phi) - \phi(1-\phi) \left(\frac{\sigma_L^2}{1+\sigma_L^2} + 1 \right) &< 0 \\ -\sigma_L^2 - \phi - \phi(1-\phi) \frac{\sigma_L^2}{1+\sigma_L^2} &< 0. \end{aligned}$$

Result 1 *It is Π -maximizing for a manager with a commitment technology to be resolute.*

Proof. If $\frac{\partial E\Pi}{\partial \sigma_p^2} < 0$ when evaluated at $\sigma_p = 1$, then it is welfare-increasing for the manager to believe that the first-period signal variance is lower than it actually is.

$$\frac{\partial E\Pi}{\partial \sigma_p^2} \Big|_{\sigma_p=1} = -\sigma_L^2 - \phi - \phi(1-\phi) \frac{\sigma_L^2}{1+\sigma_L^2}$$

Since this expression is always negative, resoluteness ($\sigma_p < 1$) is always welfare-maximizing. ■

Result 2 *The optimal level of resoluteness with commitment is lower than without it.*

Proof: We prove this by substituting in the optimal level of resoluteness with no commitment σ_p^* from (4) into the first-order condition in the environment with commitment. We show that the resulting first-order condition is negative. Since the second derivative is negative, a value of the first order condition lower than zero implies that the level of no-commitment resoluteness is higher than what is optimal in the commitment setting.

Substitute the optimal resoluteness $\sigma_p^{-2} = 2 + \phi(2-\phi)\sigma_L^{-2}$, which is equivalent to $\sigma_p^2 = 1/(2 + \phi(2-\phi)\sigma_L^{-2})$ in section 1 into the first-order condition above from section 2 delivers $FOC(\sigma_p^{nocomm})$. This

is an expression in two variables σ_L^2 and ϕ . Simply plotting the function reveals that the inequality holds for all $\phi \in [0, 1]$ and for all $\sigma_L^2 \in [0, 1000]$.

A.3 Results: Learning from Followers

Substituting for $\lambda = \sigma_p^{-2}(\sigma_p^{-2} + \beta^2 \sigma_e^{-2})$ into $\beta = (1 - \lambda)(1 - \phi)$ yields

$$\begin{aligned}\beta &= \left(\frac{\beta^2 \sigma_e^{-2}}{\sigma_p^{-2} + \beta^2 \sigma_e^{-2}} \right) (1 - \phi) \\ \beta \sigma_p^{-2} + \beta^3 \sigma_e^{-2} &= \beta^2 \sigma_e^{-2} (1 - \phi)\end{aligned}$$

One solution to this equation is $\beta = 0$. The others can be found by dividing through by β and using the quadratic formula.

$$\beta^2 \sigma_e^{-2} - \beta \sigma_e^{-2} (1 - \phi) + \sigma_p^{-2} = 0$$

$$\begin{aligned}\beta &= \left[\sigma_e^{-2} (1 - \phi) \pm \sqrt{\sigma_e^{-4} (1 - \phi)^2 - 4 \sigma_e^{-2} \sigma_p^{-2}} \right] / 2 \sigma_e^{-2} \\ &= \frac{1}{2} \left[1 - \phi \pm \sqrt{(1 - \phi)^2 - 4 \sigma_e^2 \sigma_p^{-2}} \right]\end{aligned}$$

This means that

$$\lambda = \frac{\beta}{1 - \phi} = \frac{1}{2} \left[1 \pm \sqrt{1 - 4 \sigma_e^2 \sigma_p^{-2} (1 - \phi)^{-2}} \right]$$

The organization's expected payoff is the same as in section 1, except that σ_L^2 is replaced with $\beta^{-2} \sigma_e^2$.

$$E\Pi = -(1 - \lambda)^2 (2 \beta^{-2} \sigma_e^2 + \phi(2 - \phi)) - \lambda^2$$

Next, substitute $\beta^{-2} = (1 - \lambda)^{-2} (1 - \phi)^{-2}$ to get an expression with only λ and parameters.

$$E\Pi = -2(1 - \phi)^{-2} \sigma_e^2 - (1 - \lambda)^2 \phi(2 - \phi) - \lambda^2$$

Then, take a partial derivative of this payoff with respect to resoluteness in order to derive the

optimal level of resoluteness.

$$\frac{\partial E\Pi}{\partial \sigma_p^2} = [2(1 - \lambda)\phi(2 - \phi) - 2\lambda] \frac{\partial \lambda}{\partial \sigma_p^2}$$

We know that a more resolute leader always puts more weight on his prior belief.

$$\frac{\partial \lambda}{\partial \sigma_p^2} = \frac{\partial}{\partial \sigma_p^2} \frac{\sigma_L^2}{\sigma_L^2 + \sigma_p^2} = \frac{-\sigma_L^2}{(\sigma_L^2 + \sigma_p^2)^2}$$

Thus, $\frac{\partial \lambda}{\partial \sigma_p^2} < 0$. The partial derivative is negative at $\sigma_p^2 = 1$, meaning that some resoluteness is optimal if

$$\begin{aligned} (1 - \lambda)\phi(2 - \phi) &> \lambda \\ \phi(2 - \phi) &> \frac{\lambda}{1 - \lambda} \\ \phi(2 - \phi) &> \frac{1}{\beta^2 \sigma_e^{-2}}. \end{aligned}$$

This proves proposition 4.

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